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# DESCRIPTION

Thermosyphon device, cooling and heating device and method using the thermosyphon device, and plant cultivating method using the thermosyphon device

## Technical Field

[0001] This invention relates to a thermosyphon. More particularly, this invention relates to a double tube type thermosyphon device that is used by passing an inner tube, through which a thermal source fluid flows, through an outer tube and that is multifunctional to be usable either for cooling or for heating, relates to a cooling and heating device using the thermosyphon device, relates to a cooling and heating method using the thermosyphon device, and relates to a plant cultivating method using the thermosyphon device.

## Background Art

[0002] Although a thermal converter, such as a heat pump, in which heat exchange efficiency falls in proportion to the smallness of a temperature difference between heat exchange fluids is known, a thermosyphon has recently come into practical use. The thermosyphon is capable of conveying a large amount of heat in a state of keeping the temperature difference therebetween small while utilizing an evaporation or

condensation phase change. The thermosyphon can be fundamentally regarded as a form of the heat pipe, and has an excellent heat transfer characteristic and temperature uniformity that are features of the heat pipe. For example, Japanese Published Unexamined Utility Model Application No. S62-136777 discloses a conventional example of a heat pipe (thermosyphon) of a double tube type. The device disclosed by the publication has a double-tube structure. In the device, one of either the inner circumferential surface of an inner tube and the outer circumferential surface of an outer tube is used as a heat receiving surface, and the other circumferential surface is used as a heat radiating surface. A heat medium, which is vaporized by receiving heat from the heat receiving surface and which radiates heat to the heat radiating surface by condensation, is contained in a hermetically-closed space formed between the inner tube and the outer tube. With the structure, a heat transfer area of the heat receiving part and that of the heat radiating part are designed to be large, and the device is intended to be reduced in size and to improve heat transfer efficiency.

Patent Document 1: Japanese Published Unexamined Utility Model Application No. S62-136777 (see the claim for utility model registration, FIG. 1)

Disclosure of Invention

Problems to be solved by the invention

[0003] In the Document 1 mentioned above, for example, when the outer circumference of the outer tube is heated by supplying a high temperature fluid to the inner tube, a practical-level function to heat the outer area around the outer tube cannot be fulfilled, because an area where the heat medium (operating liquid) comes into contact with the surface of the inner tube is small and because the heat transfer coefficient and the heat transportation limit of the outer wall of the inner tube are low as shown in FIG. 2 of the Document 1. The device disclosed by the Document 1 has a structure in which the outer circumference of the outer tube receives heat at a high temperature and radiates the heat toward the inner circumference of the inner tube. In the thus structured device, the inner tube is required to be eccentrically disposed above the outer tube, and, in accordance with the place at which the device is used, a determination must be made of whether a tube arrangement is performed for heating or cooling the area around the tubes when the device is installed. When switching between cooling and heating is performed after the device is installed, there has been a fear that major construction work must be performed for a change in the tube arrangement. A possible countermeasure to the

problem is to attach wicks, such as wire nets or sintered metals, made of a porous material to the outer wall of the inner tube and to the inner wall of the outer tube so as to return the operating liquid to an evaporating portion. However, it is difficult to maintain a state in which these wicks are in close contact with the tube walls. Thus, there has been a problem in the fact that production and adjustment in installation cannot be easily performed or in the fact that high cost is entailed because the tubes must be made of the same material as a container in connection with electrolytic corrosion. Additionally, because of thermal resistance caused by the structure of the porous wick or by insufficient adhesion of the wick to the tube wall, an effect desired enough to be put to practical use can be hardly achieved especially when the area around the outer tube having a high temperature is cooled. Therefore, generally, the thermosyphon is used only for warming or heating the outside of the tube in most cases.

[0004] The present invention has been made in consideration of the foregoing problems. It is therefore an object of the present invention to provide a thermosyphon device for cooling and warming (heating) the outside of the device enabling, by an extremely simple structure, the easy installation operation, elimination of the need of adjusting operation, a reduction

in manufacturing cost, and an increase in heat transportation efficiency, provide a cooling and heating device using the thermosyphon device, provide a cooling and heating method using the thermosyphon device, and provide a plant cultivating method using the thermosyphon device. It is another object of the present invention to provide a thermosyphon device capable of cooling and heating the outside of the device at the level of practical use by changing a thermal source fluid in spite of being a single device, provide a cooling and heating device using the thermosyphon device, provide a cooling and heating method using the thermosyphon device, and provide a plant cultivating method using the thermosyphon device. It is still another object of the present invention to provide a thermosyphon device superior to a conventional thermosyphon in a function to cool and heat the outside of the device, provide a cooling and heating device using the thermosyphon device, provide a cooling and heating method using the thermosyphon device, and provide a plant cultivating method using the thermosyphon device.

Means for solving the problems

[0005] To achieve the objects, the present invention is a double tube type thermosyphon device in which an inner tube 14 is disposed to be longitudinally passed through an outer

tube 12 disposed to be horizontally long, in which a working space S defined between the outer tube 12 and the inner tube 14 is provided with an operating liquid Q and is hermetically closed, and in which heat exchange is performed between an outside and an inside of the outer tube 12 while allowing a thermal source fluid U to flow through the inner tube 14. The double tube type thermosyphon device is characterized in that a large number of circumferentially-formed narrow concave grooves G are formed both in an inner wall surface 121 of the outer tube 12 facing the working space S and in an outer wall surface 141 of the inner tube 14 facing the working space S; and the operating liquid Q is raised in a circumferential direction of the wall surface (121, 141) by capillary attraction via the narrow concave grooves G, and is evaporated on an evaporating portion of either of the inner wall surface 121 of the outer tube and the outer wall surface 141 of the inner tube, whereas the operating liquid is condensed on the other wall surface, so that the outside of the outer tube is cooled or heated. The thermosyphon device of the present invention is a double tube type thermosyphon device disposed in the lateral direction. The operating liquid is raised by the capillary attraction of many narrow concave grooves in the circumferential direction of the inner wall surface of the outer tube and the

outer wall surface of the inner tube that face the hermetically closed working space, and is evaporated by being brought into direct contact with either tube wall that receives heat. The groove width of the narrow concave groove, the groove cross-sectional shape thereof, the pitch interval thereof, whether the groove is a spirally continuous groove or a one-loop ended groove, and whether the groove is continuous or intermittent in the longitudinal direction of the tube may be arbitrarily determined as long as a function by which the operating fluid is raised in the circumferential direction with the aid of surface tension and capillary attraction is secured. Water or ammonia, instead of alcohol, may be used as the operating liquid. Additionally, the material of the tube may be arbitrarily determined in accordance with the conditions of a location to be applied in consideration of durability and corrosion resistance. The thermosyphon device of the present invention can be used as a device for cooling and warming from under the floor of a house or a building, a device for heat exchange with other fluids or gases, and a device for various cooling and warming (heating) operations.

[0006] Preferably, the narrow concave groove has a groove width Wg shown in a predetermined mathematical expression as an allowable maximum groove width, and has a predetermined groove

depth Hg under the condition of the groove width.

[0007] Preferably, in that case, the thermosyphon device is of an eccentric double tube type in which the inner tube 14 has an axial center CS located at a position deviated from an axial center CL of the outer tube 12 and in which the axial center CS of the inner tube 14 is located below the axial center CL of the outer tube.

[0008] Additionally, the present invention is a cooling and heating device that uses the thermosyphon device 10 of any one of claims 1 to 3 and that performs switching between a cold fluid and a hot fluid serving as thermal source fluids U, and cools and heats the surroundings of the device as a single device.

[0009] Additionally, the present invention is a double tube type thermosyphon device 101 or 102 in which an inner tube 14 is disposed to be longitudinally passed through an outer tube 12 disposed to be horizontally long, in which a working space S defined between the outer tube 12 and the inner tube 14 is provided with an operating liquid Q and is hermetically closed, and in which heat exchange is performed between an outside and an inside of the outer tube 12 while allowing a thermal source fluid U to flow through the inner tube 14. The double tube type thermosyphon device is characterized in that a large number of circumferentially-formed narrow concave grooves G are formed

either in an inner wall surface 121 of the outer tube 12 facing the working space S or in an outer wall surface 141 of the inner tube 14 facing the working space S; and the operating liquid Q is raised in a circumferential direction of the wall surface (121, 141) by capillary attraction via the narrow concave grooves G, and is evaporated on an evaporating portion of either of the inner wall surface 121 of the outer tube and the outer wall surface 141 of the inner tube, whereas the operating liquid is condensed on the other wall surface, so that the outside of the outer tube is cooled or heated.

[0010] Additionally, the present invention is a cooling and heating method using a double tube type thermosyphon in which an inner tube is disposed to be longitudinally passed through an outer tube disposed to be horizontally long, in which a working space defined between the outer tube and the inner tube is provided with an operating liquid and is hermetically closed, and in which heat exchange is performed between an outside and an inside of the outer tube while allowing a thermal source fluid to flow through the inner tube. The double tube type thermosyphon is characterized in that a large number of circumferentially-formed narrow concave grooves are formed both in an inner wall surface of the outer tube facing the working space and in an outer wall surface of the inner tube facing

the working space; the operating liquid is always borne on the tube surfaces by capillary attraction through the narrow concave grooves; and the outside of the outer tube is cooled or heated in accordance with the thermal source fluid while guiding the operating liquid upwardly and downwardly on the surface of each tube.

[0011] Additionally, the present invention is a plant cultivating method carried out by burying the thermosyphon device of any one of claims 1 to 4 in plant cultivating soil.

Effect of the Invention

[0012] According to the thermosyphon device of the present invention, in the double tube type thermosyphon device in which the inner tube is disposed to be longitudinally passed through the outer tube disposed to be horizontally long, in which the working space defined between the outer tube and the inner tube is provided with the operating liquid and is hermetically closed, and in which heat exchange is performed between the outside and the inside of the outer tube while allowing the thermal source fluid to flow through the inner tube, the large number of circumferentially-formed narrow concave grooves are formed both in the inner wall surface of the outer tube facing the working space and in the outer wall surface of the inner tube facing the working space; and the operating liquid is raised

in the circumferential direction of the wall surface by capillary attraction via the narrow concave grooves, and is evaporated on the evaporating portion of either of the inner wall surface of the outer tube and the outer wall surface of the inner tube, whereas the operating liquid is condensed on the other wall surface, so that the outside of the outer tube is cooled or heated. Therefore, the thermosyphon device of the present invention can be easily produced by an extremely simple structure without using a mesh wick, or the like, that is expensive and has difficulty in being attached. Although the thermosyphon device of the present invention is produced at low cost, the surroundings of the device can be cooled and heated by an efficient heat transfer. Additionally, the operation to cool or heat the surroundings can be freely selected and performed merely by changing the thermal source fluid to be supplied to the inner tube.

[0013] Additionally, since the narrow concave groove has the groove width Wg as an allowable maximum groove width, and has the predetermined groove depth, a horizontally-mounted double tube type thermosyphon that does not require the work of closely attaching a mesh wick onto the inside of the tube and that has a simple structure formed at low cost can be put to practical use.

[0014] Additionally, since the thermosyphon device is of an eccentric double tube type in which the inner tube has the axial center located at a position deviated from the axial center of the outer tube and in which the axial center of the inner tube is located below the axial center of the outer tube, the operating liquid is efficiently evaporated from the narrow concave grooves formed in the outer wall surface of the inner tube, and is condensed on the entire outer wall surface including the grooves and parts other than the grooves at a condensing step, and hence excellent heat transportation efficiency can be obtained.

[0015] Additionally, since the cooling and heating device is structured that uses the thermosyphon device of claim 1 or claim 2 and that performs switching between a cold fluid and a hot fluid serving as thermal source fluids so as to cool and heat the surroundings of the device as a single device, the cooling and heating device can be effectively used while freely performing switching between cooling and heating by installing the device in various locations required to cool and heat the surroundings.

[0016] Additionally, according to the present invention, in the double tube type thermosyphon device in which the inner tube is disposed to be longitudinally passed through the outer

tube disposed to be horizontally long, in which the working space defined between the outer tube and the inner tube is provided with the operating liquid and is hermetically closed, and in which heat exchange is performed between the outside and the inside of the outer tube while allowing the thermal source fluid to flow through the inner tube, the large number of circumferentially-formed narrow concave grooves are formed either in the inner wall surface of the outer tube facing the working space or in the outer wall surface of the inner tube facing the working space; and the operating liquid is raised in a circumferential direction of the wall surface by capillary attraction via the narrow concave grooves, and is evaporated on the evaporating portion of either of the inner wall surface of the outer tube and the outer wall surface of the inner tube, whereas the operating liquid is condensed on the other wall surface, so that the outside of the outer tube is cooled or heated. Therefore, the surroundings can be effectively cooled and heated when necessary, even in the double tube type thermosyphon in which the narrow concave grooves are formed either in the inner wall surface of the outer tube or in the outer wall surface of the inner tube.

[0017] Additionally, according to the present invention, in the cooling and heating method using the double tube type

thermosyphon in which the inner tube is disposed to be longitudinally passed through the outer tube disposed to be horizontally long, in which the working space defined between the outer tube and the inner tube is provided with the operating liquid and is hermetically closed, and in which heat exchange is performed between the outside and the inside of the outer tube while allowing the thermal source fluid to flow through the inner tube, the large number of circumferentially-formed narrow concave grooves are formed both in the inner wall surface of the outer tube facing the working space and in the outer wall surface of the inner tube facing the working space; the operating liquid is always borne on the tube surfaces by capillary attraction via the narrow concave grooves; and the outside of the outer tube is cooled or heated in accordance with the thermal source fluid while guiding the operating liquid upwardly and downwardly on the surface of each tube. Therefore, the surroundings of the device can be cooled and heated with a simple structure at the level of practical use without using a mesh wick that is expensive and has difficulty in being attached. Additionally, the operation to cool or heat the surroundings can be freely selected and performed merely by changing the thermal source fluid to be supplied to the inner tube.

[0018] Additionally, since the present invention is the

plant cultivating method carried out by burying the thermosyphon device of claim 1 or claim 2 in plant cultivating soil, the growth of tame plants can be promoted, and expensive plants, such as highland vegetables, can be cultivated especially in level ground or in other various regions.

Brief Description of Drawings

[0019] FIG. 1 is a partial longitudinal sectional view of a thermosyphon device according to a first embodiment of the present invention.

FIGS. 2(a), 2(b), and 2(c) are enlarged explanatory drawings showing various ways to form narrow concave grooves.

FIGS. 3(a), 3(b), 3(c), and 3(d) show various cross-sectional examples of the narrow concave grooves.

FIG. 4 is an explanatory drawing for explaining a structure of the thermosyphon device according to the first embodiment and an operation performed during cooling.

FIG. 5 is an explanatory drawing for explaining the structure of the thermosyphon device according to the first embodiment and an operation performed during heating as in FIG. 4.

FIG. 6 is a partial explanatory drawing for explaining an example of the connection between the thermosyphon devices of FIG. 1.

FIG. 7 is a partially-cutaway perspective view when the thermosyphon device of FIG. 1 is installed as an underfloor heating and cooling device.

FIG. 8 is a cross-sectional explanatory view of a thermosyphon device according to a second embodiment of the present invention.

FIG. 9 is a cross-sectional explanatory view of a thermosyphon device according to a third embodiment of the present invention.

Description of reference symbols

[0020] 10, 101, 102 Thermosyphon device

12 Outer tube

14 Inner tube

16 Narrow concave groove group

17 Narrow concave groove group

121 Inner wall surface of outer tube

141 Outer wall surface of inner tube

G Narrow concave groove

Q Operating liquid

S Working space

Wg Groove width

Hg Groove depth

Best Mode for Carrying Out the Invention

[0021] A description will be hereinafter given of embodiments of a thermosyphon device according to the present invention with reference to the accompanying drawings, together with a cooling and heating device using the thermosyphon device and a cooling and heating method using the thermosyphon device. The thermosyphon device of the present invention is a cooling and heating means for cooling and heating the surroundings of the device by a cold fluid or a hot fluid flowing through an inner tube such that a working space between the inner and outer tubes contains an operating liquid and is hermetically closed, and the heat transfer area of the outer tube is widely secured. In the embodiment, the thermosyphon device does not require a step of closely attaching a wick, especially a mesh wick, to the inner wall surface of the tube, and is capable of cooling and heating the outside of the tube by smooth heat transportation through the tube.

[0022] FIG. 1 is a longitudinal sectional view of the thermosyphon device according to a first embodiment of the present invention. As shown in FIG. 1, the thermosyphon device 10 includes an outer tube 12 elongated horizontally, an inner tube 14 passed through the outer tube 12 in the longitudinal direction, a working space S defined between the outer tube 12 and the inner tube 14, an operating liquid Q contained in

the hermetically-closed working space S, and narrow concave groove groups 16 and 17 having a large number of circumferentially-formed narrow concave grooves G in an inner wall surface 121 of the outer tube 12 and in an outer wall surface 141 of the inner tube 14, respectively.

[0023] In the embodiment, the outer tube 12 is shaped like a horizontally long hollow cylinder, and is made of aluminum. The inner tube 14 made of the same material as the outer tube 12 is disposed in parallel with the outer tube 12, and is passed through the outer tube 12 in the longitudinal direction. As shown in FIG. 4 and FIG. 5, the inner tube 14 is eccentrically disposed slightly below the center inside the outer tube 12. Each end of the outer tube 12 is closed with an end wall, such as a cap, 18 in a state in which the working space S defined between the outer tube 12 and the inner tube 14 contains the operating liquid Q, so that the inside thereof is watertightly sealed. As shown in FIG. 4 and FIG. 5, the operating liquid Q is quantitatively contained to such a degree as to soak a part of the inner tube 14 in the fluid, more specifically, as to soak half the inner tube 14 or less than half in the fluid. The thermosyphon device in the embodiment is of an eccentric double tube type in which the inner tube 14 has its axial center CS situated at a position deviated from the axial center CL

of the outer tube 12 and in which the inner tube 14 has its axial center CS located below the axial center CL of the outer tube 12. A thermal source fluid U is supplied to the inner tube 14. A hot source fluid is caused to flow through the inner tube 14 when the outside of the outer tube 12 is heated, whereas a cold source fluid is caused to flow therethrough when the outside of the outer tube 12 is cooled.

[0024] The operating liquid Q contained in the working space S is an operating fluid that transports heat while performing a phase change between an evaporating portion and a condensing portion in the hermetically closed space. For example, in the embodiment, alcohol is contained.

[0025] A feature of the present invention is that a large number of circumferentially-formed narrow concave grooves G are formed both in the inner wall surface 121 of the outer tube 12 that faces the working space S and in the outer wall surface 141 of the inner tube 14 that faces the working space S, so that the evaporation efficiency and the heat transportation efficiency of the operating liquid Q are improved. Especially in the embodiment, the device 10 shaped like a horizontally long cylinder is used, and switching between heating and cooling is effectively freely performed to heat and cool the surroundings of the device 10 while using the gravity action.

[0026] FIGS. 2(a), 2(b), and 2(c) are enlarged views of a part of the inner wall surface 121 of the outer tube 12 or the outer wall surface 141 of the inner tube 14. In the embodiment, as shown in FIG. 2(a), a narrow, continuous spiral groove G is formed both in the inner wall surface 121 of the outer tube 12 and in the outer wall surface 141 of the inner tube 14 with a predetermined pitch in the longitudinal direction of each tube. The narrow concave groove G is formed long in the circumferential direction of each of the horizontally long outer and inner tubes, for example, when attention is paid to one round of the groove. A large number of narrow concave grooves G formed in the inner wall surface of the outer tube and a large number of narrow concave grooves G formed in the outer wall surface of the inner tube are grouped as a first narrow concave groove group 16 and a second narrow concave groove group 17, respectively.

[0027] The narrow concave groove G is a liquid-film spreading means for creating a uniform operating-liquid film distribution, which is substantially even in amount, on the entire surface of the tube wall by raising the operating liquid Q contained in the working space S along the groove G with the aid of capillary attraction. In the embodiment, the whole of the surface of the tube is covered with slight stripes of the

operating liquid in that case. The groove width Wg and the groove depth Hg of the narrow concave groove G are set so that the operating liquid Q can rise on the surface of the tube by capillary action. It is recommended to make the groove width smaller if specifications are fixed. For example, in one embodiment, the groove width is set at 0.2mm, and the groove depth is set at 0.2mm when the inner diameter of the outer tube is 27mm, and the outer diameter of the inner tube is 12mm. The pitch between the grooves is set at 0.2mm. For example, water or ammonia, instead of alcohol, is sometimes used as the operating liquid. The groove width and the groove depth are determined in consideration of the surface tension of these fluids. There is no need to fixedly select these concrete sizes when the device is structured. In consideration of workability, processing efficiency, economy, etc., in forming the grooves, the sizes may be arbitrarily selected within a range enabling a sufficiently practicable pump-up function of the operating liquid. The maximum groove width Wg with respect to a tube diameter in which the operating liquid can rise by capillary attraction is obtained by the following mathematical expressions (3) and (1):

Formula 3

[0028]

$$\frac{2\sigma}{Wg}\cos\theta\min \geq \rho_l gD \qquad (3)$$

Formula 4

[0029]

$$Wg \leq \frac{2\sigma\cos\theta\min}{\rho_l gD} \qquad (1)$$

where Wg is the groove width of the narrow concave groove, σ is the surface tension of the operating liquid, θmin is a minimum contact angle, ρl is the density of the operating liquid, g is gravity acceleration, and D is a tube diameter (maximum capillary height). Herein, the groove depth Hg is shown by the following expression (2).

Formula 5

[0030]

$$Hg \geq \frac{Wg}{2} \qquad (2)$$

However, numerical values other than those shown in the above expressions may be set with a certain degree of allowable width as far as the function mentioned above can be secured. FIGS. 3(a), 3(b), 3(c), and 3(d) show various groove shapes that can be selected as the narrow concave groove G. It is permissible to select rectangular grooves (U-shaped grooves) of FIG. 3(a), V-shaped intermittent grooves of FIG. 3(b), V-shaped continuous grooves (sawtooth-like grooves) of FIG.

3(c), U-shaped grooves of FIG. 3(d), and arbitrarily shaped grooves within a range where the function mentioned above can be fulfilled. Although, concerning the circumferential direction of the tube, the groove in the embodiment is a continuous spiral groove, the groove may be loop type grooves each of which is ended by one round as shown in FIG. 2(b). Additionally, the groove may be intermittently formed in the longitudinal direction of the tube in any case as shown in FIG. 2(c).

[0031] Next, a description will be given of the operation of the thermosyphon device 10 according to the embodiment with reference to FIG. 1, FIG. 4, and FIG. 5. For convenience of description, for example, the thermosyphon device 10 according to the embodiment is used as a floor cooling and heating device disposed on the undersurface of a wood flooring as shown in FIG. 7. FIG. 4 shows the operation of the thermosyphon device 10 carried out when the floor is cooled during the summer at a high indoor temperature. In this case, cold water, which is a cold source fluid, is circulated and supplied into the inner tube 14 by means of a driving mechanism via a pipe, not shown, that is connected in a loop manner outside the tube. The cold water is produced by, for example, a chiller or a heat pump system not shown. In FIG. 4, the outer wall surface of

the outer tube 12 serves as a heat receiving surface that receives heat at a high temperature (for example, 30°C or more), whereas the inner wall surface of the inner tube 14 serves as a heat radiating surface. The operating liquid Q contained in the working space S between the outer tube 12 and the inner tube 14 rises on the inner wall surface 121 of the outer tube 12 by capillary attraction (s1), and adheres like a film onto the whole of the inner wall surface of the outer tube 12. The liquid-phase operating fluid is brought into contact with the inner wall surface 121 of the outer tube 12 heated at a high temperature around the tube, and is evaporated (s2). The operating fluid then changes into a vapor phase, and diffuses into the working space S. The operating liquid that has changed into a vapor phase is brought into contact with the outer wall surface 141 of the inner tube 14 through which the cold water flows, is then cooled, is then condensed (s3), then flows down in the circumferential direction along the narrow concave groove G of the outer wall surface of the inner tube 14, and returns to an operating-liquid reservoir 20. The operating liquid in the liquid reservoir rises on the inner wall surface 121 of the outer tube 12, then adheres like a film onto the whole of the inner wall surface of the outer tube 12, is then evaporated to diffuse into the working space, and is condensed on the outer

wall surface of the inner tube. The cycle is repeated, so that the area around the outer tube is cooled. In the embodiment, a large number of narrow concave grooves are formed in the inner wall surface 121 of the outer tube 12 in the longitudinal direction of the tube and long in the circumferential direction thereof. The operating liquid is stored in each narrow concave groove like a stripe. Therefore, heat from the outside of the outer tube is transferred directly to the operating liquid, and the operating liquid is efficiently evaporated because the operating liquid, which is slight and even in amount, is uniformly distributed and is caused to adhere onto the surface of the tube. Additionally, the operating liquid is pumped up by capillary attraction. Especially in the embodiment, a large number of circumferentially-formed narrow concave grooves are formed both in the inner wall surface of the outer tube and in the outer wall surface of the inner tube. Additionally, the operating liquid is always borne by the tube surfaces via the narrow concave groove, and the operating liquid is guided upwardly and downwardly on the surface of each tube. Therefore, the operating liquid can smoothly rise by capillary attraction and smoothly flow down in the form of a condensed liquid phase. The outer tube heated from the surroundings comes into direct contact with a thin liquid film of the operating liquid in the

narrow concave groove, which is a part of the outer tube, and evaporates the liquid film. Therefore, thermal resistance is extremely small, and the heat transfer coefficient of the evaporating portion is greatly improved. Additionally, the operating liquid is supplied to the evaporating portion by the pumping action caused by the capillary attraction of the narrow concave groove, and, structurally, the axial center CS of the inner tube 14 is situated below the axial center CL of the outer tube 12. Therefore, the amount of operating liquid to be required is small. Additionally, since almost all of the outer wall of the inner tube is in contact with vapors, the heat transfer of the condensing portion can be synergistically improved. In this case, the inner wall surface 121 of the outer tube serves as an evaporating portion, whereas the outer wall surface 141 of the inner tube serves as a condensing portion. For example, when the device is used during sleeping time in summer, it is recommended to perform cooling so as to reach approximately 27°C to 28°C by supplying cold water to the inner tube, because an area near the back of an inactive sleeping person is cooled. Therefore, it is easy to determine and execute the cooling setting that enables this. For example, a floor or the surface of a "tatami" mat can be easily cooled to approximately 27°C to 28°C by supplying water of approximately 15°C to the inner

tube, and can be, of course, cooled to a temperature lower than that.

[0032] FIG. 5 shows a case in which the floor is heated under the low temperature of winter. In this case, for example, warm water or hot water, which is a hot source fluid, is supplied into the inner tube 14 through a boiler or a warm or hot water generating device not shown. In this case, the inner wall surface of the inner tube 14 serves as a heat receiving surface, whereas the outer wall surface of the outer tube comes into contact with a cool air and serves as a heat radiating surface. The operating liquid Q rises on the outer wall surface 141 of the inner tube 14 by capillary attraction (s21), and adheres like a film onto the entire outer wall surface of the inner tube 14. The liquid-phase operating fluid is brought into contact with the outer wall surface 141 of the inner tube 14 heated by a high temperature fluid flowing through the inner tube, is then evaporated (s22), then changes into a vapor phase, and diffuses into the working space S. The operating liquid that has changed into the vapor phase is brought into contact with the inner wall surface 121 of the outer tube 12 that is in contact with a cool air, is then cooled, is then condensed (s23), then flows down in the circumferential direction along the narrow concave groove G of the inner wall surface of the

outer tube 12, and returns to the operating-liquid reservoir 20. During the repetition of this cycle, the operating liquid is stored like a stripe in each of the large number of narrow concave grooves formed in the outer wall surface 141 of the inner tube 14. The operating liquid is efficiently evaporated because heat from the inside of the inner tube is transferred directly to the operating liquid and because the operating liquid, which is slight and even in amount, is uniformly distributed and is caused to adhere onto the surface of the tube wall. Additionally, the operating liquid is pumped up by capillary attraction, and the heat transfer of the evaporating portion is improved so as to effectively heat the surroundings of the outer tube. In this case, the outer wall surface 141 of the inner tube serves as an evaporating portion, whereas the inner wall surface 121 of the outer tube serves as a condensing portion. For example, an indoor floor or the surface of a tatami mat under the room temperature of approximately 15°C can be heated to approximately 25°C by supplying warm water of approximately 60°C into the inner tube.

[0033] As described above, in the embodiment, many circumferentially-formed narrow concave grooves are formed both in the inner wall surface of the outer tube and in the outer wall surface of the inner tube. Therefore, especially

an operation to heat or cool the surroundings of the device can be freely set merely by performing switching between a hot fluid and a cold fluid that are thermal source fluids flowing through the inner tube, and hence the single device can be practically used as a device for both heating and cooling.

[0034] FIG. 7 shows an installation example in which the thermosyphon device 10 is placed on the undersurface of an indoor flooring and is used as a floor heating and cooling device. The thermosyphon device 10 is embedded in a gap of heat insulating mats 24 laid on the undersurface of a floor 22 so as to heat or cool the floor 22. In this case, when the thermosyphon devices are connected together as needed, projection parts of the inner tubes are respectively inserted into and connected to ends of a hose 26 made of a plastic flexible tube that has high strength and corrosion resistance, for example, as shown in FIG. 6. Therefore, even when several or dozens of communicating bent tubes are arranged as shown in FIG. 7, the device can be easily installed, and can be easily maintained.

[0035] Next, a description will be given of a thermosyphon device 101 according to another embodiment of the present invention with reference to FIG. 8 and FIG. 9. The same reference symbols as in the first embodiment is given to the same element of the thermosyphon device, and an overlapping description of

the same element is omitted. As in the first embodiment, the thermosyphon device 101 of FIG. 8 according to the second embodiment is a double tube type thermosyphon device installed to be horizontally long. In the thermosyphon device 101, a large number of circumferentially-formed narrow concave grooves G are formed only in the inner wall surface 121 of the outer tube 12 that faces the working space S. The outer wall surface 141 of the inner tube 14 is merely a smooth cylindrical surface. In this case, an operating liquid film adheres onto the inner wall surface of the outer tube by capillary attraction via the narrow concave grooves G formed in the inner wall surface of the outer tube as in the first embodiment. Therefore, when the surroundings of the device are cooled, cooling is effectively performed in the same manner as in FIG. 4 of the first embodiment. As shown in FIG. 9, in a thermosyphon device 102 according to a third embodiment, a large number of circumferentially-formed narrow concave grooves G are formed only in the outer wall surface 141 of the inner tube 14 that faces the working space S. The inner wall surface 121 of the outer tube 12 is merely a cylindrical inner surface. In this case, the operating liquid film adheres onto the outer wall surface of the inner tube by capillary attraction via the narrow concave grooves G formed in the outer wall surface of the inner tube as in the first embodiment.

Therefore, when the surroundings of the device are warmed or heated, warming or heating can be effectively performed by the same effect as in FIG. 5 of the first embodiment

[0036] If the thermosyphon device according to the first or second embodiment described above is used for plant cultivation by being buried in agricultural soil in which plants are cultivated, the plants can excellently grow, and, in particular, the soil can be reliably cooled. Therefore, the thermosyphon device is effective in cultivating highland vegetables or plants that are unsuitable for high-temperature soil. Therefore, these plants can be cultivated in level ground or in other regions.

[0037] Design examples

In an eccentric double-tube thermosyphon with circumferentially rectangular grooves in which an outer tube has an inner diameter dio of 27mm and an outer diameter doo of 30mm and in which an inner tube has an inner diameter dii of 9mm and an outer diameter doi of 12mm, the maximum heat transportation amount by the capillary pressure limit was calculated when ethanol and water were each used as an operating fluid. The maximum depth Hp of the operating liquid was 6mm, and the minimum distance Hc between the inner and outer tubes was 5.5mm.

[Design Examples 1 and 2] When the surroundings of the device are cooled at the maximum heat transportation amount during cooling (cold water is used as a fluid flowing through the inner tube), the outer tube serves as an evaporating portion, and the inner tube serves as a condensing portion. Therefore, it is recommended to calculate the maximum heat transportation amount by the capillary pressure limit of the outer tube group as the maximum heat absorption amount. Accordingly, calculated values Qmax/L(W/m) of the maximum heat transfer amount per unit length during cooling when ethanol and water are each used as an operating fluid are shown in Table 1 concerning Design Example 1 and Table 2 concerning Design Example 2. In the calculation, the operating temperature (steam temperature) Tv was 10°C. In the tables, Qmax/L(W/m) is the maximum heat transfer amount per unit length, Wg is the width of the outer tube grooves (narrow concave grooves), Hmax is the maximum capillary height, Hg is the depth of the outer tube group, Sg is the pitch between the outer tube grooves, and Ng(=1/(Wg+Sg)) is the number of the outer tube grooves per unit length.

[0038] [Table 1]

Table 1

Maximum heat transfer amount of outer tube grooves during cooling (operating fluid: ethanol)

| *Wg* [mm] | *Hmax* [mm] | *Sg* [mm] | *Hg* [mm] 0.2 | 0.3 | 0.4 | *Ng* [number/m] |
|---|---|---|---|---|---|---|
| 0.2 | 29.0 | 0.2 | 111 | 339 | 614 | 2500 |
| | | 0.3 | 89 | 271 | 491 | 2000 |
| | | 0.4 | 74 | 226 | 409 | 1667 |
| | | 0.5 | 63 | 194 | 351 | 1429 |
| 0.1 | 57.9 | 0.2 | 248 | 499 | 763 | 3333 |
| | | 0.3 | 186 | 374 | 572 | 2500 |
| | | 0.4 | 149 | 299 | 458 | 2000 |
| | | 0.5 | 124 | 249 | 381 | 1667 |

Unit: W/m

[0039] [Table 2]

Table 2

Maximum heat transfer amount of outer tube grooves during cooling (operating fluid: water)

| *Wg* [mm] | *Hmax* [mm] | *Sg* [mm] | *Hg* [mm] 0.3 | 0.4 | 0.5 | *Ng* [number/m] |
|---|---|---|---|---|---|---|
| 0.6 | 23.0 | 0.5 | - | 506 | 1461 | 909 |
| | | 1.0 | - | 348 | 1004 | 625 |
| | | 1.5 | - | 265 | 765 | 476 |
| | | 2.0 | - | 214 | 618 | 385 |
| 0.5 | 27.6 | 0.5 | 516 | 2655 | 6224 | 1000 |
| | | 1.0 | 344 | 1770 | 4149 | 667 |
| | | 1.5 | 258 | 1328 | 3112 | 500 |
| | | 2.0 | 206 | 1062 | 2489 | 400 |
| 0.4 | 34.5 | 0.5 | 1896 | 6072 | 11833 | 1111 |
| | | 1.0 | 1218 | 3903 | 7607 | 714 |
| | | 1.5 | 898 | 2877 | 5605 | 526 |
| | | 2.0 | 711 | 2277 | 4437 | 417 |

Unit: W/m

From the calculation results shown above, it is understood

that the maximum heat transfer amount can be obtained when the groove width Wg of the inner diameter side grooves of the outer tube is 0.1mm, and the groove depth Hg thereof is 0.4mm if the eccentric double-tube type thermosyphon device uses ethanol as the operating liquid during the cooling of the surroundings of the device. Therefore, it is recommended to select and determine the point where the device can effectively function in practical use by these approximate sizes. In contrast, if water is used as the operating liquid, the maximum heat transfer amount can be obtained when the groove width Wg of the inner diameter side grooves of the outer tube is 0.4mm, and the groove depth Hg thereof is 0.5mm.

[Design Examples 3 and 4] When the surroundings of the device are heated at the maximum heat transportation amount during heating (warm water is used as a fluid flowing through the inner tube), the outer tube serves as a condensing portion, and the inner tube serves as an evaporating portion. Therefore, it is recommended to calculate the maximum heat transportation amount by the capillary pressure limit of the inner tube grooves as the maximum heat radiation amount. Accordingly, calculated values Qmax/L(W/m) of the maximum heat transfer amount per unit length during heating when ethanol and water are each used as an operating fluid are shown in Table 3 and Table 4. In the

calculation, the operating temperature (steam temperature) Tv was 40°C.

[0040] [Table 3]

Table 3

Maximum heat transfer amount of inner tube grooves during heating (operating fluid: ethanol)

| *Wg* [mm] | *Hmax* [mm] | *Sg* [mm] | *Hg* [mm] 0.2 | 0.3 | 0.4 | *Ng* [number/m] |
|---|---|---|---|---|---|---|
| 0.4 | 13.4 | 0.5 | - | 155 | 500 | 1111 |
| | | 1.0 | - | 100 | 321 | 714 |
| | | 1.5 | - | 73 | 237 | 526 |
| | | 2.0 | - | 58 | 187 | 417 |
| 0.3 | 17.9 | 0.5 | 101 | 623 | 1449 | 1250 |
| | | 1.0 | 63 | 383 | 892 | 769 |
| | | 1.5 | 45 | 277 | 664 | 556 |
| | | 2.0 | 35 | 217 | 504 | 435 |
| 0.2 | 26.5 | 0.5 | 341 | 1059 | 1942 | 1429 |
| | | 1.0 | 199 | 618 | 1133 | 833 |
| | | 1.5 | 141 | 436 | 800 | 588 |
| | | 2.0 | 109 | 337 | 618 | 455 |

Unit: W/m

[0041] [Table 4]

Table 4

Maximum heat transfer amount of inner tube grooves during heating (operating fluid: water)

| *Wg* [mm] | *Hmax* [mm] | *Sg* [mm] | *Hg* [mm] 0.5 | 0.6 | 0.7 | *Ng* [number/m] |
|---|---|---|---|---|---|---|
| 1.1 | 11.9 | 1.0 | - | 488 | 1657 | 476 |
| | | 1.5 | - | 394 | 1339 | 385 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | 2.0 | - | 330 | 1123 | 323 |
| | | 2.5 | - | 285 | 967 | 228 |
| 1.0 | 13.1 | 1.0 | 577 | 3416 | 9194 | 500 |
| | | 1.5 | 462 | 2733 | 7355 | 400 |
| | | 2.0 | 385 | 2277 | 6129 | 333 |
| | | 2.5 | 330 | 1952 | 5254 | 286 |
| 0.9 | 14.5 | 1.0 | 2423 | 9298 | 21052 | 526 |
| | | 1.5 | 1918 | 7361 | 16666 | 417 |
| | | 2.0 | 1588 | 6092 | 13793 | 345 |
| | | 2.5 | 1354 | 5196 | 11764 | 294 |

Unit: W/m

From the calculation results shown above, it is understood that the maximum heat transfer amount can be obtained when the groove width Wg of the outer diameter side grooves of the inner tube is 0.2mm, and the groove depth Hg thereof is 0.4mm if the eccentric double-tube type thermosyphon device uses ethanol as the operating liquid during the warming (heating) of the surroundings of the device. Therefore, it is recommended to select and determine the point where the device can effectively function in practical use by these approximate sizes. In contrast, if water is used as the operating liquid, the maximum heat transfer amount can be obtained when the groove width Wg of the outer diameter side grooves of the inner tube is 0.9mm, and the groove depth Hg thereof is 0.7mm.

[0042] The thermosyphon device according to the present invention, the cooling and heating device and method using the

thermosyphon device, and the plant cultivating method using the thermosyphon device are not limited to the structures described in the foregoing embodiments. Modifications within a range not departing from the essence of the invention recited in the appended claims are included in the present invention.

Industrial Applicability

[0043] The thermosyphon device of the present invention can be used as a device for cooling and heating from under the floor of a house or a building, a device for heat exchange with other fluids or gases, and a device for various cooling and warming (heating) operations. Additionally, the thermosyphon device of the present invention can be used to enhance plant cultivation by being buried in plant cultivating soil.